COLD FUSION RESULTS IN BARC EXPERIMENTS

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ABSTRACT

Experiments were initiated at Trombay during the first week of April 1989 to verify the widely reported claims of the occurrence of cold fusion. A large burst of $\approx 2 \times 10^7$ neutrons was first detected on April 21st with a Pd–Ni electrolytic cell. The neutron counting rate, averaged over a 5 minute interval, was a couple of orders of magnitude larger than that of background count rates. In this experiment the tritium level in the D_2O electrolyte jumped from the initial stock solution value of 2.6 Bq/ml to $\approx 5.6 \times 10^4$ Bq/ml, an increase by over four orders of magnitude. The total quantity of tritium generated corresponds to $\approx 10^{16}$ atoms suggesting a neutron to tritium channel branching ratio of less than 10^{-8} in cold fusion. Significant quantities of neutrons and tritium were also observed to be produced in gas loaded Ti and Pd samples. Autoradiography of D_2 loaded Ti disc targets have shown a number of hot spots indicating uneven distribution of tritium production in the near–surface region. On the whole the Trombay experiments have unequivocally confirmed the occurrence of cold fusion reactions both in Pd and Ti metallic lattices loaded with deuterium.

1. D_2O ELECTROLYTIC CELL EXPERIMENTS

Experiments to confirm the cold fusion phenomenon /1,2/ were initiated at Trombay during the first week of April 1989. A readily available commercial (Milton–Roy) electrolytic cell /3/ with Pd–Ag alloy tubes as cathodes and Ni as anode, originally meant for the generation of H_2 gas was adapted for the electrolysis of 5M NaOD in D_2O. Both a bank of BF_3 detectors embedded in paraffin and a proton recoil fast neutron detector (NE 102A) were employed to look for possible neutron emission. The first burst of neutrons was detected on 21st April 1989 when the cell current attained 60 amps. Later the current increased to 100 amps and the cell became overheated, resulting in the built–in trip circuit automatically switching off the power. This was followed by a big burst of neutrons approximately two orders of magnitude larger than background levels during a 5 minute interval. (The BF_3 counter measured 17,758 counts/300s and NE 102A scintillator 25,872 counts/300s as compared to average background values of $\approx$ 65 and 650 respectively). Fig.1 shows plots of the neutron counts data from the two detectors. From the efficiency of the neutron detection system measured using a standard Cf–252 source ($\approx 2 \times 10^4$ n/s), it was surmised that $\approx 2 \times 10^7$ neutrons were emitted during that five minute interval.

A number of other D_2O electrolytic cells with Pd or Ti cathodes of different geometries and designs have also been set up at Trombay, but the current capacities of these cells are lower. Neutron and tritium production has been confirmed in all these cells as well (See Table I).

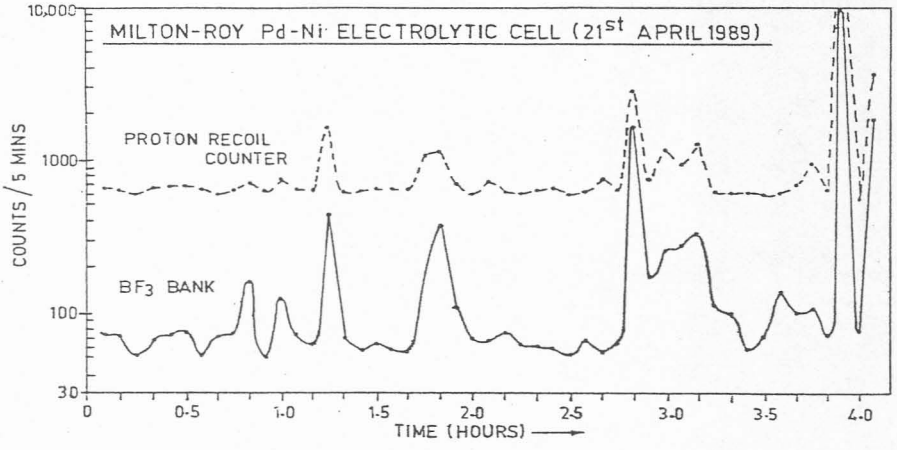

Fig.1. Neutron Counts Data From Two Detectors Using Milton–Roy Pd–Ni Electrolytic Cell (21st April 1989)

2. MEASUREMENT OF TRITIUM LEVELS IN D_2O ELECTROLYTE

The tritium levels in the D_2O electrolytes after a few days of continuous operation of the cells were measured by two seperate expert groups (belonging to the Isotope and Health Physics Divisions of BARC) who have been engaged in this type of work for over two decades. Well known liquid scintillation counting techniques applicable for low energy beta emitters were used, taking the following precautions: (a) ^{40}K free counting vials were employed to minimize background counts. (b) For higher count rate cases, 0.1 to 2 ml of sample was added to the scintillator while for low count rate samples $\approx$ 10 ml was used. In the higher concentration samples pH was reduced by diluting them with double distilled water, in order to minimise chemiluminiscence as well as quenching effects. Independently, whenever possible, these values were cross–checked with results obtained after "chemiluminiscence cooling". (c) Commercially available Instagel scinitillation cocktail was preferred over Dioxane as a solvent to minimize chemiluminiscence interference effects.

Prior to the commencement of electrolysis samples of the initial electrolyte were saved and counted along with each sample drawn during the course of the experiment. To compute the excess tritium produced in each run, the following points were taken into account: (a) Initial tritium concentration in the stock D_2O; (b) To be on conservative side the tritium that is carried away by the D_2 gas stream during electrolysis was neglected even though it is known that above 20^0C the (T/D) ratio in the gas stream is comparable to that in the liquid phase and (c) Dilution effects due to periodic make–up of D_2O. Table I presents the tritium yields measured in some of the electrolytic cell experiments conducted at Trombay.

3. MULTIPLICITY SPECTRUM OF NEUTRON EMISSION

It is of interest to establish the multiplicity spectrum of neutron emission i.e. whether the neutrons are emitted individually (one at a time) or in sharp bursts of 10 or more at a time. The number of neutron pulses issuing from a bank of BF_3 counters (embedded in paraffin) monitoring the Milton–Roy electrolytic cell was totalled over 10 ms sampling intervals and stored in a personal computer. There were 1000 such sampling intervals during a real time of 5 minutes. Data was simultaneously also recorded from a paraffin encased bank of ^3He neutron detectors placed at a distance of $\approx$ 1.5 m from the cell, serving as a background monitor. The data accumulated during periods of significant neutron emission were statistically analysed to yield the probability distribution of neutron counts. It may be readily inferred from Table II which presents one such result, that neutron emission essentially obeys Poisson distribution. However it is also found that occasionally more than 10 neutron counts are registered in a single 10 ms interval. The background monitor has never yielded such high multiplicity events even over a one week period of continuous monitoring. This points to the occurrence of nuclear events wherein 100 or more

TABLE I: TRITIUM PRODUCTION IN ELECTROLYTIC COLD FUSION EXPERIMENTS

Sl No	DIVISION /GROUP	CATHODE MATERIAL /SHAPE	ELECT–ROLYTE	VOL. OF D_2O SOLN.	MAX. CELL CURRENT (Amps)	TRITIUM LEVELS (Bq/ ml) INITIAL	FINAL (10^3)	TRITIUM PRODUCTION. (Bq) (10^6)	Atoms (10^{14})
1.	HWD/NtPD	Pd–Ag Tubes (M–R Cell)	5M NaOD in D_2O	250 ml	100	2.6	55.6	13.9	80
2.	,,	,,	,,	,,	,,	10.0	4.4	1.1	6
3.	HWD/DD/ NtPD	Pd Sheets	,,	1000 ml	65	2.0	7.0	7.0	40
4.	,,	Ti Rod	,,	135 ml	40	2.0	1.8	0.24	1.3
5.	ACD–(i)	Pd Cylinder	0.1 M LiOD in D_2O	45 ml	1–2	31.3	16.6	0.75	4
6.	ACD–(ii)	Pd Ring	,,	65 ml	1–3	18.1	8.8	0.57	3

neutrons are emitted in a single sharp burst, probably under a 100μs in duration. Such occasional neutron "flashes" are also reported to have been observed by Menlove et al at LANL /4/.

4. GAS LOADED TITANIUM TARGET EXPERIMENTS

Following reports of neutron emission having been detected by the Frascati group /5/ with pressurised D_2 gas loaded Ti shavings, two variants of this experiment were carried out at Trombay. One group (Chemistry Division) followed the Frascati procedure with ≈ 20 g of cut Ti pieces and D_2 gas pressures increasing upto 50 bars. The temperature was cycled between 77 K and room temperature. The neutron detection system comprised of 24 ^{3}He counters arranged in a well like array and having a counting efficiency of ≈ 10%. The first neutron emission from this set up occurred on 3rd June when the temperature increased to ambient value from 77 K with simultaneous evacuation. The neutron count rate reached a peak value of 3900/40s as compared to initial background levels of 60 per 40s. The neutron emission phase lasted for about 30 minutes. The same charge was then subjected to temperature cycling between 77 K and 300 K leading to emission of ≈ 6.5 X 10^6 neutrons in all over a 7 hour duration. A similar neutron output lasting for ≈ 2 hours was recorded subsequently when the sample temperature was raised gradually with simultaneous evacuation. Fig.2. depicts the neutron yield variation measured during this run.

In a second variation of the gas loading experiment, small machined targets (discs, cones, cylinders etc) of Ti metal (mass between 0.2 to 1 g) were individually loaded with D_2 gas by heating them to 900^0 C in D_2 atmosphere at 1 Torr pressure and then switching off the power to the induction coil. D_2 gas was absorbed by the Ti target in the course of a minute or so during its cooling. The quantity of D_2 absorbed could be measured from the observed pressure drop. This corresponded to ≈ 10^{19} molecules of D_2 gas, indicating a gross (D/Ti) ratio of hardly 0.001. However it is believed that most of the absorbed D_2 gas is accumulated in the near surface region. Some targets did show statistically significant excess–over–background neutron counts during the one minute duration of gas absorption. A disc shaped Ti button loaded on Friday 16th June began emitting neutrons on its own, almost 50 hours after loading. It produced ≈ 10^6 neutrons over a 85 minute active phase. The background neutron counter did not show any increase in counts during this time.

TABLE II: MULTIPLICITY DISTRIBUTION OF NEUTRON COUNTS IN 10 ms INTERVALS

(Milton–Roy Electrolytic Cell: Friday 16th June 1989)

Time	BF_3 Counter Bank (Signal)															^{3}He Counter Bank (Background)		
(Hrs)	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	1*	2*	3*
18.55	124	21	4	1	–	–	–	–	–	–	–	–	–	–	–	2	1	–
19.00	54	9	1	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
19.05	335	54	7	2	1	–	–	–	–	–	–	–	–	–	–	4	–	–
19.10	320	82	10	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–
19.15	243	13	4	–	1	–	–		–	–	–	–	–	–	–	5	–	–
19.20	315	35	3	1	–	–	–	–	–	–	–		–	–	–	4	–	–
19.25	295	24	–	1	–	–	–	–	–	–	–	–	–		–	5	–	–
19.30	492	51	3	2	–	–	–	–	–	–	–				–	4	–	–
19.35	447	42	2	1	–	–	–	–	–	1	–	1	–	–	–	9	–	–
19.40	104	13	4	–	–	1	–	–	–		–	–			–	5	–	–
19.45	355	49	1	1	–	1	–	–	–	–	–		–	–	–	33	1	–
19.50	395	99	16	2	–	–	–	–	1	–	–	–	–	–		22	3	–
19.55	55	24	7	33	2	1	1	1	1	1	2	2	1	–	5	6	2	–

(*) Starred numbers represent the multiplicity of counts obtained in a single 10 ms interval. The respective frequency of occurrence (per 1000 gated intervals) is given in the corresponding column below.

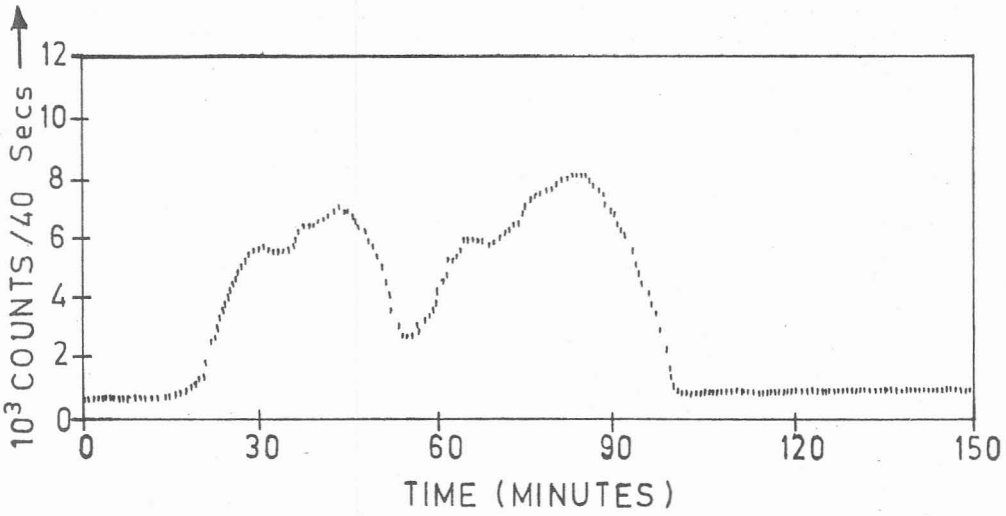

Fig.2. Neutron–Yield Variation During Desorption Mode: D_2O Gas Loaded Titanium–Experiments (7^{th} June 1989)

5. AUTORADIOGRAPHY OF DEUTERATED TITANIUM TARGETS

Since tritium which emits betas of 18 Kev (end point energy) has been found to be the primary product of cold fusion, it may be expected that autoradiography of deuterated Ti targets may give very useful information in the form of space resolved images. Deuterated Ti targets in which cold fusion reactions were suspected to have occurred were placed over a standard medical X–ray film and exposed overnight. On developing, the radiographs of deuterated Ti discs showed about a dozen intense spots randomly distributed within the disc boundary, besides a large number of smaller spots, especially all along the periphery forming a neat ring of dots (see Fig.3). Repeated measurements with the same disc target with exposure times varying from 10 to 40 hours gave almost identical patterns of spots, indicating that the tritium containing regions were well entrenched in the face of the titanium lattice. Spectral analysis of the X–ray emissions from such targets using a Si(Li) detector clearly showed the characteristic K_α(4.51 Kev)and K_β(4.931 Kev) peaks of titanium excited by the betas from tritium decay.

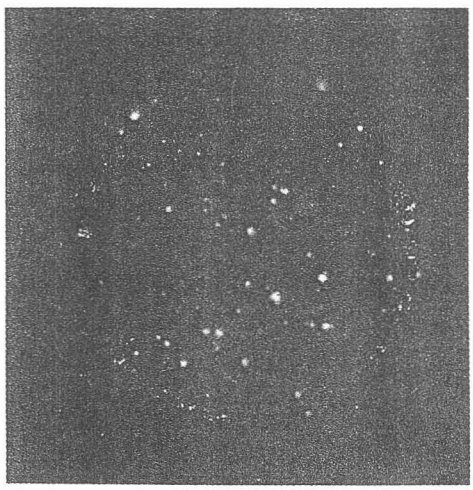

Fig.3. Typical Autoradiograph of a Deuterated Ti Disc Showing Regions of Tritium Concentration

6. SUMMARY AND CONCLUSIONS

Investigations of cold fusion phenomena carried out at Trombay during the first three months of the "cold fusion era", namely April to June 1989, have positively confirmed the occurrence of (d–d) fusion reactions in both electrolytic and gas loaded Pd and Ti metal lattices at ambient temperatures. Neutron emission has been observed even when the current to the electrolytic cell is switched off or in case of gas loaded Ti targets when no externally induced perturbation such as heating/ cooling/ evacuation etc is effected. The main findings of the Trombay investigations todate may be summarised as under:

(a) Tritium is the primary product of cold fusion reactions, notwithstanding the fact that the tritium, if any, entrapped inside the palladium electrodes has yet to be quantitatively assessed. Thus cold fusion may be characterised as being essentially "aneutronic" with a neutron to tritium channel branching ratio of less than 10^{-8}.

(b) Neutron emission both from electrolytically loaded Pd and gas loaded Ti is basically Poisson in nature i.e. the neutrons are emitted one at a time. However it is not clear whether the neutrons are generated in the (d–d) fusion reaction itself or whether it is produced in a secondary reaction involving the energetic protons or tritons. In this context it would be of interest to look for the possible presence of 14 Mev neutrons in cold fusion experiments.

(c) Occasionally nuclear events do appear to take place wherein over a 100 neutrons are generated in a single sharp burst. Viewed in the light of the branching ratio estimate of 10^{-8} noted above, this leads to the intriguing conclusion that a chain reaction involving as much as 10^{10} fusion reactions occurs within a time span of a 100 μs.

(d) Autoradiography of gas loaded Ti targets demonstrates in a simple and elegant manner not only the occurrence of cold fusion, but also the production of tritium. The estimated tritium to deuterium isotopic ratio in these targets is several orders of magnitude higher than in the initial stock D_2O and as such cannot be explained away on the basis of preferential absorption of tritium by the titanium as may be suspected. The existence of highly localised regions (hot spots) on the target surface wherein tritium is concentrated as well as the occurrence of spots all along the periphery of the disc, points to the important role of lattice defect–sites in the absorption process or in the accumulation of tritium following migration after its formation, at least in titanium.

The very high probability for the tritium branch in cold (d–d) fusion reactions would indicate processes of neutron transfer across the potential barrier as postulated by Oppenheimer over half a century ago /6/ and elaborated on more recently by Rand McNally /7/. If neutron transfer as envisaged by these authors does take place so easily, it may have many implications for the future of nuclear technology, for the deuterium nuclide might very well do the work which free neutrons do in present day fission reactors. In the context of the emerging energy production scenario, aneutronic fusion reactions such as this may give rise to new fusion technologies providing a cleaner energy source for the twenty first century.

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